Effects Of Langmuir Circulations On The Plankton

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Grant No. N00014-94-1-0176

My objective in this work was to establish whether the plankton is affected by Langmuir Circulations (LCs). LCs are wind and wave induced flows in the mixed layer (ML) and comprised of counter-rotating, helical cells aligned with the wind. They occur widely and frequently. While their surface manifestation is relatively well known, their dynamics and relation to the plankton are less well understood. Of particular interest is the effect of flow on zooplankton distributions. The challenge was to measure plankton distributions simultaneous with the physical flow and property distributions.

I participated in the second FLIP cruise (April-May 1996) of the ONR Marine Boundary Layer (MBL) program, approximately 60 miles off Monterey, with marine meteorologists and physical oceanographers. My general approach was to sample the plankton and its environment continuously in the vertical, by profiling between the top and base of the ML with a 1-3 min cycle time, and at a single depth within the ML, at higher frequency. Measurements were made of temperature, salinity, and sigma-*t* (CTD), flow (acoustic Doppler velocimeter, ADV), chlorophyll *a* concentration (chlorophyll absorption meter, CHLAM), and zooplankton concentration (plankton pump collections; optical plankton counter, OPC).

LCs occurred and were quantified by our measurements. Conditions progressed from benign, with a stratified upper ocean, to strong winds and high waves, with well-developed LCs, followed by abatement. Forcing was quantified by estimating LC convergent velocity from wind stress and wave height time series. LCs were manifest in the temperature distribution of our profiler data. In particular, in the time-depth domain, sections within LCs showed cool water apparently entrained upward from the base of the mixed layer to the surface. These patterns persisted on the scale of hours. Temperature at a single depth within well-developed LCs varied in a periodic fashion over a range of the order 0.02 deg C. Such measurements have enabled us to construct a physical context in which to interpret our biological observations.

Chlorophyll *a* initially showed well defined vertical gradients in concentration and layers in the horizontal. Effects of internal waves were apparent. Chlorophyll *a* appeared well-mixed by LCs.

Initial, objective analysis of our OPC data for the zooplankton showed pattern in the time-depth domain in both stratified (initial) and LC (mid- to late-term) conditions within the experiment. Pattern in stratified conditions showed variation in the vertical and layers in the horizontal. Pattern in LCs showed patchiness in the mixed layer, in both the horizontal and vertical. The challenge was been to establish whether the pattern in LCs from objective analysis was real or artifact.

The 120-sec, low-pass filtered, vertical velocity (w_{120sec}) time series, when superimposed on the time (abscissa) – depth (ordinate) plot of temperature, clearly varies with temperature. That is, when 'tongues' of deep, cool water penetrate from the top of the thermocline towards the surface within the mixed layer, w_{120sec} is positive upwards, and vice versa. In essence, as hoped and planned, we appear to have successfully measure the residual vertical velocity due to LCs amidst

the much greater velocity variation due to surface gravity waves and swell. This, I believe, may be the first time in which LC residual vertical velocity has been measured acoustically. Importantly, it had been done in the open ocean with concurrent biological measurements.

We have rigorously analyzed pattern in our data using geostatistics. Dr. Nicolas Bez of the Ecole des Mine, Paris, is expert in the use of variograms in the analysis of spatial pattern and collaborated in this work. We found that (a) variograms are appropriate to describe pattern in data from instruments on the profiler (time-depth and distance-depth) as well as at fixed depth (time, distance); (b) significant pattern exists for temperature in LCs in the horizontal but not along profiles in the vertical, within the mixed layer; (c) fixed CTD and profiling CTD yield consistent time series; and (d) no significant pattern exists in LCs for zooplankton-sized particles sensed by the OPC or collected with the plankton pump. In essence, it appears that the observed LCs were sufficiently intense to mix the zooplankton and disperse patches. That is, velocities of the LCs appear to exceed those of the zooplankters, precluding patches formation and maintenance.

The means by which we have viewed the plankton and its physical environment in this study is novel and appropriate for future investigations. Our profiling instruments and software have been used in an ONR-funded study of a deep aggregation of copepods in the Santa Barbara Basin. A modified, *in situ* OPC is now in routine use in the California Cooperative Fisheries Investigations (CalCOFI). Data acquisition software created for use in this project, using LabVIEW in real-time to acquire, archive, and display data, has proven useful in other endeavors. Perhaps the three most significant results of our work are, first, discovery of the zooplankton patch dispersal by LCs in the open ocean; second, the value of concurrent, high-resolution physical and biological measurements on comparable time and space scales; and, third, the need for rigorous statistical analysis of such data.

Publications and Presentations

Checkley, D.M., Jr., T. Cooper, and C. Lennert. 1996. Plankton pattern within and below the surface mixed layer. EOS 76.

Checkley, D.M., Jr., T. Cooper, and C. Lennert. Plankton pattern within and below the surface mixed layer. Ocean Sciences Meeting, San Diego, CA. February, 1996.

Checkley, D.M., Jr., and T. Cooper. Effects of Langmuir Circulations on the plankton. ONR Marine Boundary Layer ARI Workshop, San Diego, CA. October, 1996.

Osgood, K.E., and D.M. Checkley, Jr. 1996. Observations of a deep aggregation of *Calanus pacificus* in the Santa Barbara Basin. Limnol. & Oceanogr., 42:997-1001.

Osgood, K.E., and D.M. Checkley, Jr. 1997. Seasonal variations in a deep aggregation of *Calanus pacificus* in the Santa Barbara Basin. Mar. Ecol. Prog. Ser., 148:59-69.

NOTE: The primary journal article(s) in which this work will be reported are in preparation. This is due largely to the recent successes in correction of the ADV data and application of geostatistics to our ADV, CTD, and OPC data.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	4/26/00	Final Technical Report / 11/1/93 - 12/31/99

4. TITLE AND SUBTITLE
Effects Of Langmuir Circulations On The Plankton

5. FUNDING NUMBERS
ONR
N00014-94-1-0176

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Attn: Dr. James Eckman
800 North Quincy Street
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The objective in this work was to establish whether the plankton is affected by Langmuir Circulations (LCs). LCs are wind and wave induced flows in the mixed layer (ML) and comprised of counter-rotating, helical cells aligned with the wind. Observations were from FLIP in April-May 1996. The plankton and its environment were sampled by continuous vertical profiling and at a single depth within the ML. In LCs, 'tongues' of deep, cool water penetrating the mixed layer coincided with acoustically-sensed upward velocities associated with LCs. Chlorophyll a showed vertical gradients and layers in stratified conditions and was well-mixed by LCs. Geostatistical analysis with variograms showed significant pattern existed for temperature in LCs in the horizontal but not in the vertical and no significant pattern in LCs for the sampled zooplankton. In essence, it appears that the observed LCs were sufficiently intense to mix the zooplankton and disperse patches. Significant results of our work are, first, discovery of the zooplankton patch dispersal by LCs in the open ocean; second, the value of concurrent, high-resolution physical and biological measurements on comparable time and space scales; and, third, the need for rigorous statistical analysis of such data.

14. SUBJECT TERMS
Biology, physics, plankton, Langmuir cell, circulation, flow, pattern, pelagic, mixed layer, oceanography, wind, waves, weather

15. NUMBER OF PAGES
3

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unrestricted	Unrestricted	Unrestricted	None